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XV.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXIX.—EXPERIMENTS ON THE BLAKE MICROPHONE CONTACT.

By George W. Patterson, Jr.

Presented by Charles R. Cross, January 11, 1888.

In the spring of 1887, Mr. H. J. Tucker and I experimented on the contact in the Blake microphone transmitter, with the object of determining, if possible, the relation between the normal pressure at the contact, and the current in the receiver of the telephone, which was placed in the secondary circuit of an induction coil in the usual manner.

In the following pages I shall give a brief description of our apparatus, and some account of our experiments, with the results reached; and in conclusion I shall deduce, from a consideration of the apparatus and the laws of electricity, equations for curves of pressure and current which are similar to those obtained in experiment.

In our laboratory work we had the advantage of a knowledge of the work which had been done in the preceding two years by Messrs. Page, Lewis, and Hopkins, under the direction of Professor Cross, only a portion of which is published.*

The object of our work being to determine the variations in the secondary undulatory current caused by variations in the normal pressure at the microphone contact, we required some simple way of regulating the contact pressure, — some way, if possible, which would admit of reproducing precisely the same results from the same conditions of pressure and sound. This latter we failed to accomplish satisfactorily.

Having removed the door, including the microphone contact and the mouthpiece, from the transmitter, we fastened it to the table, leaving space between it and the table for an organ pipe (512 complete vibrations per second), which we used as our source of sound.

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* See Proc. Am. Acad., vol. xxi. p. 248.

To obtain a sound of constant intensity, we blew the pipe by means of an air blast driven by the engine in the Rogers Building. The air was regulated by two pressure regulators, one allowing part of the air to escape, the other balancing the air pressure by a column of mercury. The height of the mercury could be changed at will.

The pressure in the Blake contact is regulated by the attachment of the carbon electrode to a spring, whose tension is adjusted by a screw. In addition to the spring, which we used for preliminary adjustment, we applied pressure by means of a lever arm carrying a scale-pan at its centre, one end of which rested on the electrode; the other carrying a knife-edge resting on glass, acted as a fulcrum. The scale-pan was covered by a piece of velvet, in order that the addition of weights might cause no jar at the contact. In our experiments we found that any attempt to take off weights had the effect of disturbing the adjustment of the contact to such an extent as to break the series. This same result was frequently brought about by the jarring of the ground from the street traffic.

We used a more powerful induction coil than that in the Blake transmitter. The resistance of its primary was 0.5 ohm, and of its secondary, 899 ohms.

We experimented on various forms of battery with varying arrangements of the cells, to observe the effect of changes in electromotive force and in resistance. The currents to be measured were very small, and consequently some extremely sensitive form of electrodynamometer was required. We used one of the Kohlrausch pattern with movable coils, which we wound of No. 40 (B. & S. gauge) double silk-covered wire. The two outer coils might be used either in parallel or in series with each other, and in either way with the inner (suspended) coil.

This dynamometer, which differed in some of its details from the instrument as ordinarily made by Hartmann, was constructed especially for experiments of this nature by Mr. Otto Scholl, the mechanician of the Laboratory.

The condition of maximum sensitiveness with coils of a given size is obtained by arranging them so that the product of the ampère-turns in the outer and the inner coils is a maximum.

In designing our inner coil, we were limited by the size of the tube in which it turned. This coil we wound with as many turns as possible, giving a resistance of 180 ohms, which was not too large for the best conditions, the resistance of the induction coil being high. We then wound two outer coils, each of 800 ohms' resistance, which were as large as it was convenient to fit on to the dynamometer.

For maximum sensitiveness, the resistance of the outer coils should be equal to one fourth of the resistance in circuit. The sensitiveness falls off much more rapidly with decrease of resistance below this point, than it does by increase of resistance above this point. The law is represented by the equation

$$Y = \frac{X}{(\alpha + \beta X^2)^2};$$

in which Y is a measure of the sensitiveness; X, the resistance per foot of the wire in terms of the resistance per foot of the wire of the standard coil; β, the total resistance of the standard coil; and α, all other resistance in circuit, about 1,100 ohms. βX^2 is the resistance of the outer coil, the resistance of a fixed weight of wire being directly as the square of its resistance per foot. Y is a maximum when $\alpha = 3 \beta X^2$.

It will be seen from the above equation, that, if the outer coils are used in series, the resistance, 1,600 ohms, is much too large; if they are used in parallel, the resistance, 400 ohms, is also large; and the instrument is 64 per cent more sensitive with the parallel arrangement. For best effect, the wire of the outer coils should have had a section 91 per cent larger, and the coils should have been used in series, or a section 4 per cent larger, and have been used in parallel. However, we found that if the outer coils were used in parallel, the dynamometer was sufficiently sensitive.

For a suspension, we finally used a platinum wire, 0.004″ in diameter, all lighter ones breaking because of the weight of the coil. The length of the wire was about twenty inches. The inner coil carried a vane, swinging in dilute sulphuric acid, by which one connection was made, the other being made by means of the suspending wire. Mercury was not used, as its surface tension would not allow free enough motion of the contact wire. The deflection of the inner coil was read by a telescope and scale, a mirror being fixed to the coil.

As the currents to be measured were alternating, it was necessary to calibrate the electro-dynamometer for alternating currents; for in rapidly alternating currents the inner coil is acted on by the outer coils only, while in direct currents the magnetism of the earth is felt also. Mr. Hopkins in his experiments had inserted a current alternator between the battery and his dynamometer, but found a great deal of trouble from leakage across the insulation. We therefore sought to calibrate the dynamometer with direct currents, and, by a mathematical consideration of the curve obtained, to construct a curve proper for alternating currents.

In calibrating this dynamometer we met with considerable difficulty, for it was far too sensitive to be put in direct circuit with the most sensitive standard galvanometer, and it could not be placed in a shunt circuit because of the impossibility of determining its equivalent resistance, the inverse electro-motive force of the sulphuric contact entering in as a doubtful element.

These difficulties were overcome by setting up the dynamometer with the planes of its outer coils east and west, connecting it in series with a very sensitive bell-magnet galvanometer, and observing the corresponding deflections. Series were taken by varying the resistance in circuit, and also reversing the current both at the battery and in the inner coil. The bell-magnet galvanometer having been calibrated by a standard instrument, we computed the currents* corresponding to the different deflections, and plotted the curves of deflection and current for the dynamometer. These curves were found to be two equal parabolas, whose equations were

$$C^2 - 1.297\,C = -0.134\,S, \qquad (1)$$

and

$$C^2 - 1.297\,C = 0.134\,S, \qquad (2)$$

C being the current in milliampères and S the scale readings in millimeters. (Figure 1.)

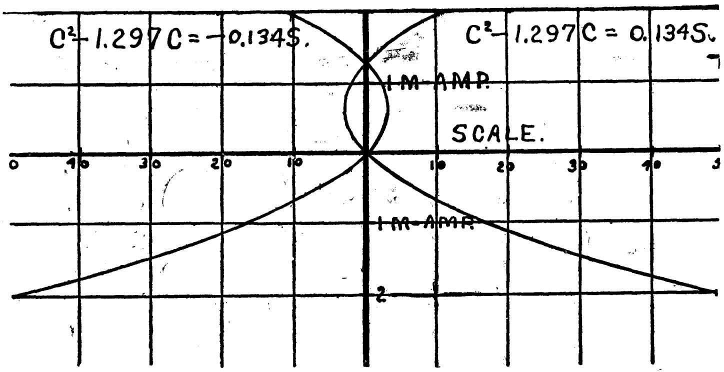

FIG. 1.

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* A variation of 0.00001 ampère in the current could be measured.

Each parabola was constructed from two series of measurements, in both of which the relative directions of the current in the outer and inner coils were unchanged, each series being represented by a branch of the parabola.

It was next necessary to find the law which the dynamometer would follow for alternating currents.

Taking the forces acting along any line passing through the centre of the coil, we have for the action between the coils a force proportional to the square of the current, and for the action of the earth's magnetism on the suspended coil a force proportional to the current. These two forces are balanced by torsion. Expressed in the form of an equation, this gives $\alpha C^2 + \beta C = \gamma$, where C is current and α, β, γ constants for that position. To obtain the same deflection we might have used a negative current, C^1, which may be expressed as $-nC$; then $\alpha\, n^2\, C^2 - \beta\, n\, C = \gamma$; from these two equations it follows that $\alpha C^2\, n = \gamma$, that is, eliminating the earth's action, a steady current of $C\sqrt{n}$ would produce equilibrium in this position. But, as $C\sqrt{n}$ is a mean proportional between the arithmetical values of the two currents which produce equilibrium in this position, we have simply to find the mean proportional for each position, and construct a new curve. Solving equations (1) and (2) we get

$$C = \frac{1.297}{2} \pm \sqrt{\left(\frac{1.297}{2}\right)^2 \pm 0.134\, S.}$$

A mean proportional between the values of C for (1) is $-0.134\, S$; for (2) it is $+0.134\, S$. Therefore, the equations for a direct current when the inner coil is free from the earth's effect are

$$C^2 = -0.134\, S, \tag{3}$$

and

$$C^2 = +0.134\, S. \tag{4}$$

(See Figure 2). In the case of an alternating current, we have a continuous variation in strength; but if we understand by C^2 the mean value of the square of the current, and not the square of its (arithmetically) mean value, which is nearly 20 per cent smaller, when the current variations are of a simple harmonic character, we may use equations (3) and (4) to express variations of current and deflection for alternating currents. In changing from (1) and (2) to (3) and (4), we have made a change in the axes only, the curves being identical.

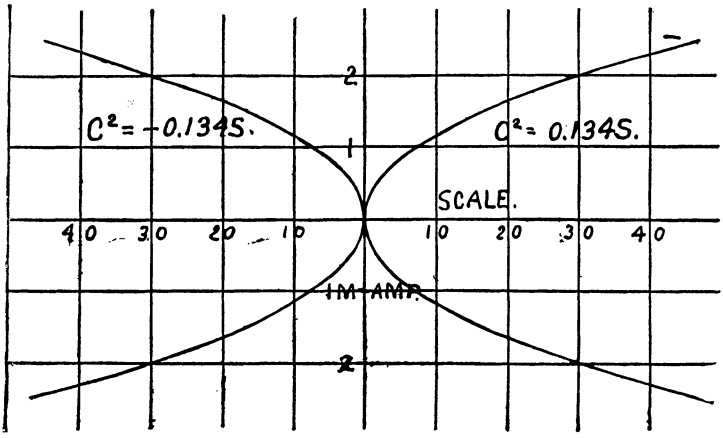

FIG. 2.

It will be seen from the demonstration that this transformation of axes without change in the form of curve is peculiar to the parabola.

The calibration being completed, we proceeded to investigate the law of relation between pressure and current, using the Dolbear and chromic acid primary batteries, and the Brush storage battery.

The pressure at the contact was adjusted by the spring until the addition of 25 mgr. would allow sound to be transmitted through the telephone; the weight was then increased, at first by additions of 250 or 500 mgr., and afterward more rapidly.* The deflections, the

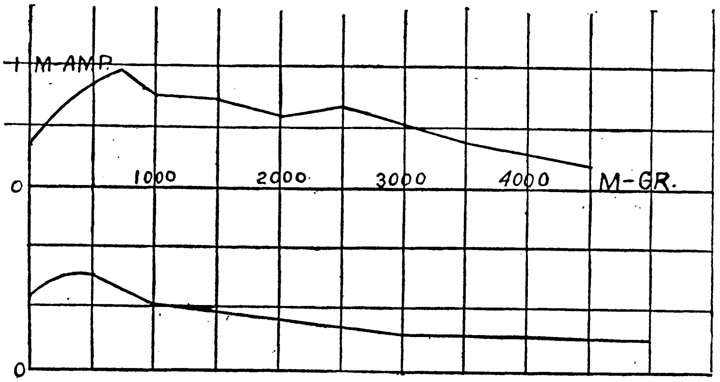

FIG. 3.

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* In some series the increment was only 25 mgr.

quality, and the intensity of the sound transmitted, were noted. The accompanying plots (Figure 3) and table will serve as examples of the series.

The values given are those of the steady currents, which, in the absence of any magnetic effects from the earth, would give the deflections observed. As the precise form of the variation of the current is uncertain, no better mode of procedure has suggested itself. The columns headed Def., C., and Wt., contain the observed deflections, the calculated currents, and the weights in the pan. These weights should be divided by 2 to obtain the pressure at the contact.

BRUSH STORAGE BATTERY, TWO CELLS IN PARALLEL.

1.				2.			
Def.	C.	Wt.	Remarks.	Def.	C.	Wt.	Remarks.
.85	.34	0	Broken sound.	2.20	.54	0	Roaring.
3.05	.64	250		4.05	.74	250	Bad.
5.30	.84	500	Loud, and beginning to be musical.	4.30	.76	500	
6.45	.93	750	Loud and good.	2.10	.53	750	Loud, and beginning to be good.
4.35	.76	1,000	Lower, and clear.	2.05	.52	1,000	
3.95	.73	1,500	Wavy.	.65	.29	3,000	Loud and good.
2.55	.59	2,000	Good.	.65	.29	4,000	Good, but growing fainter.
1.75	.68	2,500		.45	.25	5,000	
1.10	.39	3,500	Low.				
.32	.20	4,500	Very low.				

It will be noticed that the current rises very rapidly at first with this increase of pressure. At all points of this rapid rise the sound transmitted is very bad, and there are very frequent breaks with the intensity of sound employed. The maximum is soon reached, at about 1,000 mgr. pressure, and from that point the current falls off gradually. The sound becomes good soon after the maximum current is reached, and as the pressure increases the sound diminishes in intensity but improves in quality. In all our experiments the same form of curve represented the variation of pressure and current, and in all, the best sound was transmitted directly after the maximum current.

I find that this form of curve is in harmony with theory, assuming that the pressure at a microphone contact varies inversely as its resistance. The total resistance in the circuit is a constant plus the resistance of the joint. This may be expressed by the equation

$$R = \alpha + \frac{\beta}{P},$$

R meaning resistance, P pressure, and a and β constants. But

$$C=\frac{\gamma}{R},$$

C meaning current, and γ a constant; therefore

$$C=\frac{\gamma P}{aP+\beta}.$$

Suppose the sound waves due to the pipe to cause a varying pressure on the contact, whose extreme values are $\pm\,\delta$. The extreme values of the resulting current will be, in each vibration,

$$\frac{\gamma(P+\delta)}{a(P+\delta)+\beta},\ \text{and}\ \frac{\gamma(P-\delta)}{a(P-\delta)+\beta}.$$

The difference between them will be proportional to the secondary current I. The secondary current depends on the rate of change in the primary. This relation may be expressed by the equation

$$I=\Theta\left[\frac{P+\delta}{a(P+\delta)+\beta}-\frac{P-\delta}{a(P-\delta)+\beta}\right]=\frac{2\beta\delta\Theta}{a^2(P^2-\delta^2)+2a\beta P+\beta^2}.\quad(1)$$

If P is less than δ, it is evident that the electrodes will break contact, a minus pressure being impossible. In this case the current at one extreme will be 0 instead of

$$\frac{\gamma(P-\delta)}{a(P-\delta)+\beta},$$

and the secondary current I will be

$$\frac{\Theta(P+\delta)}{a(P+\delta)+\beta}.\quad(2)$$

When $P=\delta$, these two values for I are identical. The curve obtained by following (2) up to the point $P=\delta$, and (1) after that, is similar to the accompanying sketch (Figure 4).

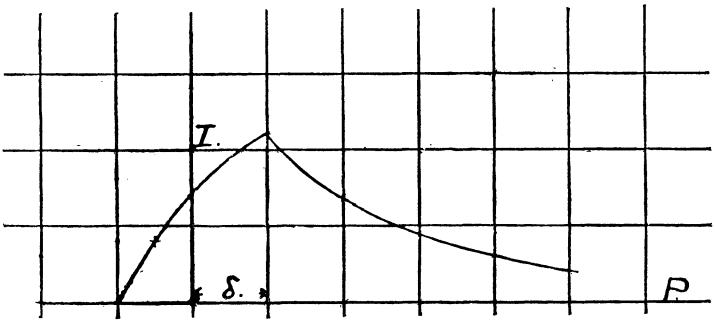

FIG. 4.

The similarity between the curves *B* and the curve *C* shows the close agreement of theory with the results observed.

The first part of the curve, corresponding to equation (2) of incomplete contact, is the curve of imperfect transmission; the last part of the curve, corresponding to equation (1) of complete contact, is the curve of good transmission.

From equations (1) and (2) it will be noticed that the pressure required for good transmission of sound is dependent on the intensity of the sound, good sound being transmitted if δ is less than P. The sound in the receiver is loudest when δ is nearly equal to P.

In experimenting with electro-motive forces greater than 3 volts, we met with unsatisfactory results. Good sound was not transmitted except under heavy pressure, and all attempts to obtain satisfactory measurements failed on account of the well-known disturbances set up in the microphone by the current itself.

In certain of our experiments the resistance of the primary circuit was diminished by joining a number of cells in parallel. The uniform result was, that the sound transmitted was louder.

The results of our experiments may be summed up as follows: —

The resistance of the primary circuit, and especially that of the battery, should be as low as possible; the pressure at the contact should be no greater than is required to transmit good sound, — that is, it should be a little greater than that required to give the maximum current; with the present form of Blake contact, no electro-motive force greater than 2 volts should be used; and, finally, the contact should be carefully guarded against jarring.

Our work should be considered, not as a complete investigation, but as part of the foundation for future work in the Rogers Laboratory; for our results have been more in the invention of methods than in the use of them. We trust that the work in which we have had a share may be successfully carried out in the future.

Rogers Laboratory of Physics,
January, 1888.